Corning Tropel (formerly Tropel Corporation)

Improving Measurement Accuracy and Speed Using Optical, Noncontact Technology

Many precision fabrication industries, such as fuel-injector and bearing manufacturing, rely on precise measurement techniques to sustain dimensional accuracy. During the early to mid-1990s, the primary technologies used to measure surface forms, particularly complex surface forms, failed to keep pace with the growing need to improve speed and accuracy through in-process measurement of these surfaces. Accordingly, Tropel Corporation, one of the world's leading small optics companies, sought to meet this need by developing its unique noncontact, optical interferometric measurement technology. In 1995, the company applied for and received funding through the Advanced Technology Program (ATP) to develop this new technology. By project conclusion in 1998, Tropel had developed a laser interferometry measuring system for complex shapes that increased measurement speed by a factor of 10 to 20 times and improved dimensional measurement accuracy by 2 to 5 times more than the mechanical measurement. Through these research and development accomplishments, Tropel was able to commercialize its CylinderMaster™ machine. Since the project ended, Tropel has sold more than a dozen machines worldwide.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 95-01-0022 were collected during July - September 2001.

Existing Measurement Instruments Were Slow and Costly

Precision manufacturing has always required a great deal of dimensional accuracy. It relies on performing exact measurements of component surfaces during the manufacturing process. Methods used for this type of measurement before the mid-1990s were reliable, but painstakingly slow and costly, causing major bottlenecks that affected the productivity of industries such as automotive and bearing manufacturing. During this time, coordinate measuring machines (CMMs) and precision roundness gauges were the backbone of general-purpose shape measurement; however, these machines had several limitations.

When a large number of points are needed to characterize a surface, the data-acquisition time becomes prohibitive, and the accuracy of the data often deteriorates because of thermal and other drifts. Data acquisition was limited to a few points per second with CMMs. Moreover, these machines did not permit in-process measurement of surfaces, which would let machine operators measure a surface before a process and make any necessary changes before completing the entire manufacturing loop. The need for greater in-process testing to improve the quality of manufacturing processes drove the evolving industry's need to measure machined part dimensions at higher speeds, with greater accuracy, and at lower costs.

Particularly challenging to the precision manufacturing industry was the need to measure complex shapes, such as cylinders and cones, which had to be measured by physical contact. At the time, most manufacturers used CMMs to perform these measurements. CMMs move tiny contact probes around the surface and build up a set of measurement

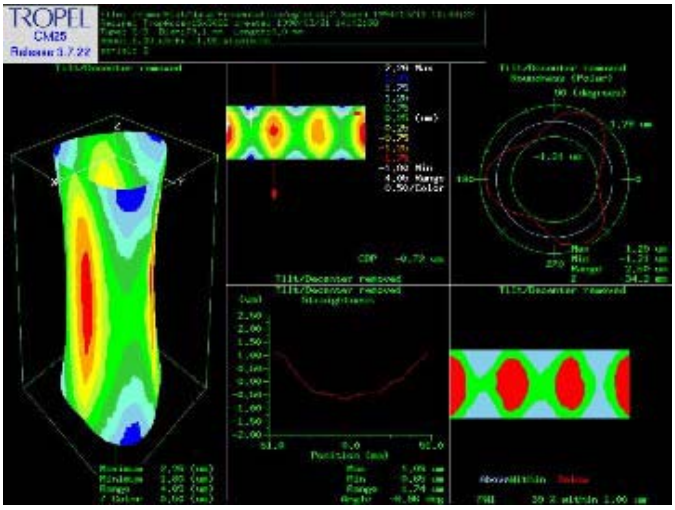
points that are used to ensure that the object measured is within certain dimensional tolerances. The process was slow, however, and could not be used for real-time control.

Measuring Complex Shapes Requires New Technology

Even companies that had mastered methods for measuring simple, flat surfaces struggled to develop new methods for measuring complex shapes. Tropel Corporation, one of the world's leading small optics companies, teamed with Cummins Engine to develop a new approach for measuring complex surfaces using optical, noncontact methods.

Particularly challenging to the precision manufacturing industry was the need to measure complex shapes, such as cylinders and cones, which had to be measured by physical contact.

Tropel proposed to investigate advanced optical interferometric methods for measuring complex machined surfaces that would allow in-process characterization of these surfaces. Interferometry had been used successfully for many years to accurately and rapidly measure simple shapes such as spheres and flat surfaces. Common optical systems, such as laser interferometry, worked well for simple surfaces because they were able to accurately create the optical wavefronts that conform to and, therefore, permit the measurement of such surfaces. However, more complex surface forms, such as cylinders and cones, could not be easily measured by these common optical components, because the components were unable to create the complex wavefronts (conical or axiconical) required to test such surfaces. Therefore, accomplishing accurate yet rapid measurements of complex surface forms was challenging. The complexity of the technology and the failures of other CMM manufacturers to develop new methods caused Tropel to seek support for its technology development efforts. In 1995, the company applied for and received ATP funding.



An example of the imaging capabilities that were possible using the CylinderMaster™ machine.

Tropel's unique approach used diffractive optics (DOs) to apply the multiplexing and noncontact advantages of laser interferometry to more complex shapes. The company planned to use DOs to produce complex wavefronts by applying the same lithography techniques that were common in the semiconductor industry for processing silicon wafers. DOs allow wavefronts to be designed or engineered with a nearly arbitrary shape from a software description. Thus, with DOs, interferometry could be used with a much broader class of surfaces, limited only by the ability to mathematically describe the desired wavefront or surface. It was predicted that replacing mechanical measurement systems with laser interferometry systems would improve the speed and accuracy of complex surface measurements.

Tropel Faces Technical and Business Barriers

The project's technical and business risks were particularly daunting for a company as small as Tropel. For example, major technical risks included the use of DOs for this type of measurement, since this technology was in its infancy at the time; the self-alignment and automatic operation elements of the proposed technology; and the fact that completing the dimensional measurements required analyzing large amounts of data.

Assuming technical success, the major business risk was that the techniques proposed were radically different from the existing ones, and no other equivalent technology existed. Tropel knew that there would be a long acceptance period before manufacturers and other end users would readily adopt these technologies.

The new technology increased measurement speed by a factor of 10 to 20 times and improved dimensional measurement accuracy by a factor of 2 to 5 times.

By project conclusion in 1998, Tropel had successfully improved measurement accuracies to the submicron level and had reduced measuring time to less than one minute. Tropel was able to develop a prototype, the CylinderMaster™, which measures shape and form, and Cummins performed tests on this prototype machine. However, as discussed earlier, the measuring machine used techniques that were very different from the techniques normally used at that time. Cummins was dissatisfied with the results of the new technology because the company had difficulty correlating measurements by the prototype machine with data obtained from existing instruments. Consequently, Cummins ended its participation in the ATP project at the testing stage.

Despite losing its strategic partner, Tropel continued developing the technology and was able to perform in-plant demonstrations. Additionally, the company disseminated its knowledge to others, allowing the University of North Carolina at Charlotte to use the machine for research purposes.

CylinderMaster™ Improvements in Speed and Accuracy Lead to Success

The new technology increased measurement speed by a factor of 10 to 20 times and improved dimensional measurement accuracy by a factor of 2 to 5 times.

These improvements allowed Tropel to find enough support for its technology to commercialize the CylinderMaster™ in 1998, shortly after the ATP project concluded.

Through this project, the company successfully developed the basis for its CylinderMaster™ product, which is now being used throughout the world.

Since then, Tropel (now Corning Tropel) has sold more than a dozen machines for $200,000 each. This success has allowed the company to establish a worldwide, three-year sales agreement with Carl Zeiss IMT for Tropel's metrology instruments business.

Conclusion

Manufacturing industries are constantly striving to improve the speed and accuracy of their processes. One major aspect involved in the process is the measurement system that is used to ensure that the parts produced are within the required dimensional tolerances.

Measurement techniques used during the time of this ATP project were fairly accurate, but painstakingly slow. To meet the need for a more precise and quicker method, Tropel sought ATP's assistance in developing its unique optical interferometric measurement technology based on diffractive optics. Through this project, the company successfully developed the basis for its CylinderMaster™ product, which is now being used throughout the world to improve the accuracy and speed with which complex shapes are measured in precision manufacturing plants.

PROJECT HIGHLIGHTS
Corning Tropel (formerly Tropel Corporation)

Project Title: Improving Measurement Accuracy and Speed Using Optical, Noncontact Technology
(Noncontact Optical Metrology of Complex Surface Forms for Precision Industrial Manufacturing)

Project: To develop a unique optical interferometric measurement technology based on diffractive optics to enable high-speed, in-process, noncontact measurement of complex shapes, such as cylinders and cones, in a manufacturing environment.

Duration: 8/1/1995-3/31/1998
ATP Number: 95-01-0022

Funding (in thousands):

ATP Final Cost	$ 924	45%
Participant Final Cost	1,115	55%
Total	$ 2,039	

Accomplishments: Through this project, Tropel accelerated the development of its optical measurement technology and achieved important milestones leading to its technological successes. The company improved dimensional measurement accuracies to the submicron level and reduced measuring time to less than one minute. The project's accomplishments also enhanced the company's reputation as an innovative optical metrology company, and they experienced a 10- to 15-percent increase in revenue and employment.

Tropel received the following five patents as a result of technology related to the ATP project:

- "Diffraction management for grazing incidence interferometer"
  (No. 5,719,676: filed April 12, 1996; granted February 17, 1998)
- "Object fixturing in interferometer"
  (No. 5,684,594: filed April 18, 1996; granted November 4, 1997)
- "Fringe pattern discriminator for interferometer using diffraction gratings"
  (No. 5,724,137: filed June 27, 1996; granted March 3, 1998)
- "Interferometric measurement of toric surfaces at grazing incidence"
  (No. 5,889,591: filed October 17,1996; granted March 30, 1999)
- "Interferometric measurement of absolute dimensions of cylindrical surfaces at grazing incidence"
  (No. 5,777,738: filed March 17, 1997; granted July 7, 1998)

The developers of the technology made several presentations and wrote numerous papers explaining the technology. The following presentations and papers are a sampling:

- Kulawiec, A.W. and J.H. Bruning, "Applications of Diffractive Optics to Three-Dimensional Surface Form Measurements," 1996 Annual Meeting of the Optical Society of America, Paper TuH3, Rochester, NY, October 20-24, 1996.
- Kulawiec, A.W., J.F. Fleig, and J.H. Bruning, "Interferometric Measurements of Absolute Dimensions of Cylindrical Surfaces," 1997 Annual Meeting of the American Society of Precision Engineering, Norfolk, VA, October 5-10, 1997.

Commercialization Status: Before this ATP project, Tropel conceived of a cylinder-measuring instrument and had established a proof of concept. Through the ATP-funded project, the company was able to develop a prototype of the metrology instrument. In 1998, after the conclusion of the ATP project, Tropel successfully commercialized its CylinderMaster™ product. They have sold two to three CylinderMasters™ ($200,000 each) per year over the past five years and have established a worldwide, three-year sales and marketing agreement with Carl Zeiss IMT for Tropel's metrology instruments business.

Outlook: Currently, the technology is aimed at a specific, high-end, precision manufacturing segment. Tropel (now Corning Tropel) expects its CylinderMaster™ to experience limited growth over the next couple of years as the firm continues to develop an increased market for the instrument. Corning Tropel is seeking to expand the development of this technology by adding new capabilities that would be useful for process manufacturing, such as the ability to measure size and diameter, in addition to measuring shape and

form. The company is exploring additional applications for its technology, such as fiber-optics packaging for the telecommunications industry.

Composite Performance Score: * * *

Number of Employees: 120 employees at project start, 260 as of September 2001

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Subcontractors and Strategic Partners:

INTI Electronics
Cummins Engine